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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

Research required to understand the impact of tactical mid-frequency sonar transmission on fish, fisheries and fisheries habitat:

Summary of Stakeholder Concerns and Prioritized Research Plan from the Workshop on Mid-Frequency Sonar and Marine Fishes

by

Dr. Andrew Read, Elliott Hazen, Lucie Hazen, and Lesley Thorne

September 2007

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13. ABSTRACT *(maximum 200 words)*

As reported in NPS-OC-07-004, analysis of public comments responding to the Draft Environmental Impact Statement (October 2005) for the proposed Undersea Warfare Training Range (USWTR) in Onslow Bay off North Carolina identified three main areas of public concern. One of these concerns, the effects on fish and fisheries habitats of mid-frequency active (MFA) sonar, further identified four sub-areas of concern: catch rates, spawning choruses, distribution and migratory behavior, and physiological effects. A workshop was held in April 2007 at Duke University to address these sub-areas of concern. The purpose of the workshop was to outline a program of research that could help determine how MFA sonar might affect fish and fisheries resources. This report summarizes the recommendations that emerged from that workshop. Specifically, a long-term research and development plan is articulated, as well as the priorities within that plan.

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Summary of Stakeholder Concerns and Prioritized Research Plan from the Workshop on Mid-Frequency Sonar and Marine Fishes

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May 31, 2007

Introduction

This report summarizes research activities that are designed to provide insight into the potential effects of tactical mid-frequency sonar training exercises on fish and fisheries. A specific area of importance will be the Undersea Warfare Training Range (USWTR) Alternative A (*i.e.*, preferred alternative) as it is an identified area that can be studied before and after installation. USWTR Alternative A is approximately 500 square nautical miles (NM) in size (20 NM by 25 NM) and lies in Onslow Bay, roughly 60 miles from the North Carolina coast (Figure 1). Training exercises will involve ship (destroyer, cruiser, and frigate), submarine, aircraft, and helicopter activity; and the use of mid-frequency sonar. Research recommendations focus specifically on determining the potential effects of mid-frequency sonar on fish and fisheries.

Tactical mid-frequency active (MFA) sonars produce sounds at frequencies between 1 and 10 kHz. Some species of fish are able to detect these sounds with their auditory systems, and sound is thought to be important to fish communication and perception of their environments (*e.g.*, learning about the “auditory scene,” including dectection of prey and avoidance of predators). However, very little is known about hearing capabilities of most marine fish species. Many species of fish are known to be able to detect and localize (*i.e.*, determine the distance and bearing of) sounds, and to discriminate between sounds. It is also known that exposure to human-generated (anthropogenic) sounds can affect hearing capabilities of at least some fish species, and can even cause temporary loss of the ability to detect sounds in the environment (either from damage to the ears or through interference “masking” of the desired signal), which may have an impact on short- or long-term survival. Thus, the intensity, duration, onset, and incidence of exposure to sounds, and how they impact the ability of fish to detect biologically relevant sounds, are important factors in considering potential impacts of mid-frequency sonar on fish in the proposed USWTR.

Stakeholder concerns on the potential effects of USWTR Alternative A activities were solicited through a public comment period held by the Navy from November 2005 through January 2006. Approximately 27,800 comments were received, of which 325 concerned sonar effects on fish and fisheries, and these are summarized in this report. Subsequently, a workshop was sponsored by the Navy and held at Duke University in April 2007, bringing together fish acoustics experts and North Carolina fisheries officials to discuss research required to address potential effects of MFA sonar activities. Substantial progress was made during the two-day workshop, and participants were able to identify and prioritize key research objectives. A summary of this workshop and its recommendations are presented below.

Summary of stakeholder concerns

To provide a comprehensive view of stakeholder concerns, the authors analyzed public comments on the USWTR Draft Environmental Impact Statement (DEIS) from October, 2005. These comments were condensed and compared to the summary received from Keith Jenkins, Naval Facilities Engineering Command, Atlantic Fleet.

There were three main areas of public concern about fish and fisheries in the proposed USWTR, as listed below in order of the number of public comments on each topic. *The authors present these concerns without any assessment of their validity.* Many respondents noted that the DEIS did not adequately incorporate existing research, but also pointed out that further research is necessary to adequately address acoustic impacts.

The following three categories of concern were raised frequently in public comments and need consideration by the Navy. The first two are outside the scope of this effort, so focus was placed on the third category of concern.

1. **Displacement of fishermen during training exercises.** Other than direct effects on fishes, the primary concern of many coastal stakeholders (particularly recreational and commercial fishermen) is that they will be required to leave the area during training exercises.

2. **Habitat modification or destruction.** Concerns were expressed about effects during construction of the USWTR as well as potential effects of discarded materials (sonobuoys, XBTs, parachutes, etc.) during training operations. Many comments noted that hard bottom habitat is important fish habitat and that such areas could be adversely affected during both construction and active operation.

3. **Short- and long- term effects on fish from mid-frequency sonar operations.** These concerns included effects on catch rates, spawning choruses, migratory behavior, hearing, survivorship, and early life history stages of fish.

   a. *Catch Rates* - Several fishermen mentioned anecdotal accounts of fish-finders reducing catch rates of large, valuable pelagic species (see list below). The comments noted that the DEIS did not identify plans to address the effects of mid-frequency sonar on these species.

   b. *Spawning Choruses* - There are many soniferous (sound-producing) fish species in NC waters and several comments noted that testing involving mid-frequency sonar could mask (obscure) mating choruses. Such an adverse effect on reproductive behavior could have deleterious population-level effects.

   c. *Distribution & Migratory Behavior* - Concerns were expressed that fish would avoid waters surrounding the USWTR, resulting in large-scale ecosystem and fishery impacts. Some comments expressed the view that such effects could occur at large spatial scales, while others were concerned with distributional or behavioral changes of fish, which could affect fishing quality in key fishing grounds within the USWTR (*e.g.*, Grouper Hole and Swansboro Hole).

   d. *Physiological Effects* - Long-term hearing loss or direct mortality have been observed in fishes exposed to loud sounds, but there is no mention in the DEIS of this past research or plans for future research in this area on the effects of exposure to mid-frequency sonars. Some respondents noted that larval stages could be particularly sensitive to such sounds.

Many comments noted that if the use of mid-frequency sonars had adverse effects on fishes, there could be important economic effects on tourism (*e.g.*, SCUBA diving), recreational, and commercial fisheries.

These four primary areas (*i.e.*, 3a through 3d) of concern formed the basis for discussion at the Workshop on Mid-Frequency Sonar and Marine Fishes. Further information was gathered in informal meetings with local fishermen and managers before the workshop to provide background and to help in formulating and refining potential research priorities.

Draft Recommendations: Workshop on Mid-Frequency Sonar and Marine Fishes 19-20 April 2007, Duke University, Durham NC

Background

The objective of this workshop was to outline a program of research that could help determine how MFA sonar might affect fish and fisheries resources. Specifically, the participants sought to describe the range of scientific concerns regarding the effects of Navy training activities using tactical mid-frequency active sonar (1-10 kHz) on fish and fisheries resources and to distill these concerns into a long-term research and development plan. Workshop participants were selected based on their expertise in acoustics, fish hearing and fisheries biology. A list of attendees is provided in Appendix A.

During the workshop, participants reviewed the mid-frequency active sonar operational procedures, current knowledge of fishes and important fisheries habitats within the proposed USWTR, recent research on the hearing capabilities of fishes, and the potential for injury or mortality associated with various sound sources, including mid-frequency active sonar. In reviewing the latter, the participants focused on the likelihood that species of interest (due to their recreational, commercial, or ecological importance) could detect the sound of, or become injured/killed as a result of emissions from tactical mid-frequency active sonars. Workshop participants recognized that fishes could exhibit a continuum of potential responses to mid-frequency sonar, ranging from direct mortality (either immediate or delayed), to injury, to behavioral changes, to increased stress levels, or that there might be no effect.

Workshop participants spent one day discussing current research on fish hearing, potential research projects that focused on measuring fish hearing capabilities, potential mortality by mid-frequency active sonar, and behavioral changes caused by exposure to active sonar signal transmissions. During the second day, participants focused on grouping these potential projects into relevant categories and ranking each of these projects based on importance, feasibility, and cost. The list of research priorities on the effects of tactical mid-frequency active sonar on fish and fisheries is comprehensive and provides an important guide to the formulation of a research plan investigating the potential impacts of mid-frequency active sonar on fish and fisheries in Onslow Bay.

After the scope of potential effects and possible research topics were identified, workshop participants broke into three small working groups and prioritized these topics. This process gave highest priorities to research programs that would provide insight into: (1) potential mortality and then (2) behavioral responses due to exposure to mid-frequency active sonar. Workshop participants were assigned randomly to the three working groups and were asked to use the criteria listed in Table 1 to rank each project with a value of 1 (most important), 2, or 3 (least important). The mean ranking from all three working groups is provided in Table 2. The complete list of research topics discussed at the workshop is presented below (without assessment or ranking) as tasks A-F.

Research Tasks (Note that the listing sequence is without assessment or ranking)

A. Resource Inventory

1. Bottom habitat mapping - Conduct surveys with multi-beam, side scan and bottom-typing sonar to comprehensively describe the distribution of important fish habitat (*e.g.*, hard and live bottom) within the proposed USWTR.

2. Fisheries resource inventory – Compile baseline data on pelagic, highly migratory, and demersal fish species from previous research conducted in the proposed USWTR; additional studies could be undertaken where previous sampling has been insufficient. Key fish species in the proposed USWTR, distilled from the DEIS comments, are listed in Table 3. This task would consist of the following:

a. Assessing and integrating existing data on the distribution of key species and their respective life stages (larvae, juveniles, adults, and spawning adults); and

b. Conducting directed studies to describe the distribution and occurrence of key species in the proposed USWTR.

B. Potential Fish Mortality

1. Swim bladder models - Model the dynamic response of swim bladders in key species (selected based on their ecological and economic importance) and life stages to insonification by mid-frequency sound as a function of the depth at which the fish live. From the model results, an assessment of potential acoustic vulnerability to mid-frequency sonar could be conducted based on calculated motion of the swim bladder and subsequent strain in the swim bladder wall and surrounding tissues.

2. Larval mortality experiments – Conduct a multi-parametric, epidemiological study of dose-response relationships for mortality (*e.g.*, LD50) of larval fish exposed to mid-frequency sonar signals using various signal parameters. This recommendation is based on the assumption that larval stages will be more sensitive to effects from mid-frequency sonar than later life stages. This work could, with the appropriate equipment, be conducted in a laboratory.

The following criteria would be used for species selection:

(a) Ease of rearing and handling in the laboratory;
(b) Presence in Onslow Bay;
(c) Recreational or commercial importance; and
(d) Utility as a model for other species (swim bladder

morphology).

The following experiments would be conducted, as appropriate:

2.1 If mortality occurs in response to exposure to mid-frequency sounds, the results would be extrapolated to assess whether larval mortality attributed to mid-frequency sonar poses a risk to the population.

2.2 If larval mortality levels are high in response to exposure to mid-frequency sounds, additional exposure experiments should be conducted on later life stages (*e.g.*, juveniles, adults)

2.3 Rearing of surviving individuals after sound exposure should be conducted to examine long-term effects on fitness (e.g., growth, developmental stage, reproduction) to fully assess potential effects of mid-frequency active sonar.

2.4 Larval fish (and fish at other life stages) killed by exposure to mid-frequency sonar should be examined by a fish pathologist to identify the cause of mortality.

C. Potential Effects on Auditory Fish Physiology

1. Mid-frequency hearing assessment - Establish hearing capabilities for key species in Onslow Bay over their whole frequency range of hearing so it becomes possible to determine if mid-frequency sonars can potentially affect hearing in any part of the detection range of the fishes being studied. Morevoer, signal levels as high as 190 dB re 1 μPa (equivalent to the highest level that may be received by a fish during an exercise in the proposed USWTR) should be used to test hearing in the mid-frequency bandwidth to ascertain whether, at these very high levels, fish can detect such sounds. Auditory brainstem response (ABR) experiments should be used to determine hearing capabilies in species amenable to such studies. Biomechanical models, based on the anatomical structure of the ear, swim bladder response to sound exposure, and other information about the auditory system, should be developed and used to estimate hearing thresholds for species for which ABR studies cannot be conducted.

a. The criteria listed in 2(a)-(d) should be used to prioritize species selection;

b. Describe the auditory anatomy of fish in Onslow Bay for species that are difficult to rear in captivity and for which hearing capabilities cannot be measured (such as large pelagic species) and develop biomechanical models to predict hearing sensitvity;

c. Measure hearing capabilities of selected species to validate predictions of hearing capability derived from biomechanical models of auditory systems in the same species, based on the approach in C.1.b. These results would then be used to assess our predictive capacity across species.

2. Threshold shifts - Determine if there are temporary threshold shifts (TTS) after exposure to high levels of sound in the mid-frequency range (1-10 kHz).

3. Auditory damage - Assess whether there is damage to tissues involved with hearing (e.g., swim bladder, sensory cells of the inner ear). Also have a fish pathologist assess whether there is damage to non-auditory tissues after exposure to the sounds used to assess TTS (as per B.2.4)

D. Potential effects on Non-Auditory Fish Physiology

1. Fish stress experiments - Perform controlled exposure experiments on and measure stress (*e.g.*, cortisol levels, hormones, growth rates, condition metrics, parasite levels, immune challenge) of fishes exposed to mid-frequency sonar.

E. Potential Effects on Fish Behavior and Distribution:

1. Behavior of small pelagics – Monitor behavioral responses of small pelagic fishes (*e.g.*, menhaden [*Brevoortia tyrannus*]) to playbacks of mid-frequency sonar in the field. This work should consider the effect of multiple exposures to mid-frequency sonar. Representative species should be chosen based on their economic and ecological importance. Potential monitoring techniques would include fisheries sonars (38-200 kHz), aerial surveys, and optical sensors.

2. Behavior of large pelagics – Monitor the behavioral responses of highly migratory species of economic interest (*e.g.*, tunas, marlins, etc.) to mid-frequency active sonar; two potential research strategies are presented.

    a. Fine-scale responses: Use digital tags to examine whether fishes perceive and respond to mid-frequency active sonar. Potential techniques include the use of acoustic recording tags (*e.g.*, D-tags), which measure sound levels received by the fish and which can be used to determine three-dimensional movement.

    b. Meso-scale responses: Monitor the movement and behavior of fishes equipped with acoustic tags using a tracking vessel or hydrophone array, or by employing pop-up archival tags to examine changes in behavior over longer time periods.

3. Soniferous fishes - Assess the potential effects of exposure to mid-frequency active sonar on sound production by soniferous fishes.

4. Demersal fishes – Use underwater video in key habitats (*e.g.*, live or hard bottom) to observe behavioral responses of demersal species to mid-frequency sonar, with particular interest in the following potential research projects:

    a. Fine-scale responses: Determine whether demersal fishes respond to mid-frequency sonar using underwater video in key habitats; and

    b. Meso-scale responses: Use tactical surface-ship sonar experiments (*e.g.*, AN/SQS 53C tactical mid-frequency transducer with Navy cooperation) to determine whether mid-frequency sonar might affect schooling behavior, spawning aggregations, or catchability. Potential techniques include the use of underwater video or the deployment of acoustic tags with hydrophone arrays.

F. Potential Effects on Fish and Fisheries

1. Additional ranges – Establish a quantitative assessment of commercial and recreational fisheries in other operational ranges (*e.g.*, the southern California Operational Area) by:

    a. Comparing catch rates within the range before, during, and after mid-frequency sonar exercises;

    b. Assessing perceptions of fishing quality using socio-economic surveys as a method for describing potential long-term effects in the proposed USWTR; and

    c. Conducting a quantitative analysis of fish abundance and distribution using fisheries-independent measures to compare these metrics in other operational ranges with appropriate control sites.

2. Socio-economic surveys – Use surveys to measure perceptions of fishing success and geographical usage in Onslow Bay prior to and following implementation of the proposed range.

3. Fleet monitoring – Use techniques such as vessel monitoring systems (VMS) or port surveys of charter boats to examine spatial and temporal variation in fishing effort prior to and following implementation of the proposed range.

4. Catch rates – Monitor standardized catch rates (*e.g.*, by using independent observers or fleet-independent surveys) of sentinel species (*e.g.*, black sea bass [*Centropristis striata*], large pelagics) prior to and following implementation of the proposed range.

5. Artificial reef test sites – Expose artificial reef sites to mid-frequency active sonar to examine the potential response of the entire artificial reef community (*e.g.*, by using diver transects, video). The existing monitoring strategy employed by the NC Division of Marine Fisheries could provide adequate baseline data, against which post-exposure data would be compared.

Explanation of research priorities

Workshop participants identified the following objectives as research priorities: conducting bottom mapping, establishing an inventory of fish species within the proposed training range, developing swim bladder models to investigate potential acoustic vulnerability of different fish species and life stages, and conducting experiments to elucidate the hearing capabilities of fish. Establishing an inventory of fish species found in the potential USWTR and identifying the distribution of fish habitat were seen as important first steps. Workshop participants agreed that investigating potential mortality of fish species through swim bladder models should be conducted before non-lethal effects of sonar were examined. Determining the hearing capabilities of key species of fish (either through direct examination or modeling) was also identified as an important starting point before conducting experiments to identify behavioral effects or evidence of auditory tissue damage or increased stress levels.

Monitoring catch rates within the proposed range and examining behavioral responses of small pelagic and soniferous fishes were also identified as important research priorities. Investigating behavioral effects on small pelagic fishes was assigned a higher priority than examining effects on larger pelagics because some small pelagics (*e.g.*, clupeids) are known to hear at mid-frequencies. Conversely, large pelagics were thought to be less likely to hear in this range. Workshop participants also noted that behavioral effects on larger fishes could be: delayed or occur over longer time scales; harder to document; or exhibited through effects on prey. The behavioral responses of soniferous fishes were identified as a priority because of the potential for masking effects of sonar on communicative signals.

Investigating behavioral effects of sonar on demersal fish species, studies of catch rates in existing Navy ranges, and dose-response relationships for larval mortality were recommended as important and feasible research tasks. The behavior of demersal species can be examined through video studies, and this approach allows behavioral effects to be recorded in some detail. Studies in other currently operational ranges would allow for a quantitative assessment of the effects of sonar on catch rates in a timely fashion. Larval fish were regarded as the most vulnerable life stage because their swim bladders are known to resonate at mid-frequencies and, as such, larval fish mortality was considered to be an important research topic.

Socio-economic surveys to measure perceptions of fishing success were considered to be less useful, potentially less statistically powerful, and less timely than the more direct means of evaluating catch rates discussed above. Similarly, an examination of the response of fish communities at artificial reef sites to exposure to mid-frequency sonar was regarded to be difficult and labor-intensive. Studies of fleet monitoring to examine variation in fishing effort and studies of fish stress were considered to be less feasible and less important biologically than other research objectives.

Figures and Tables

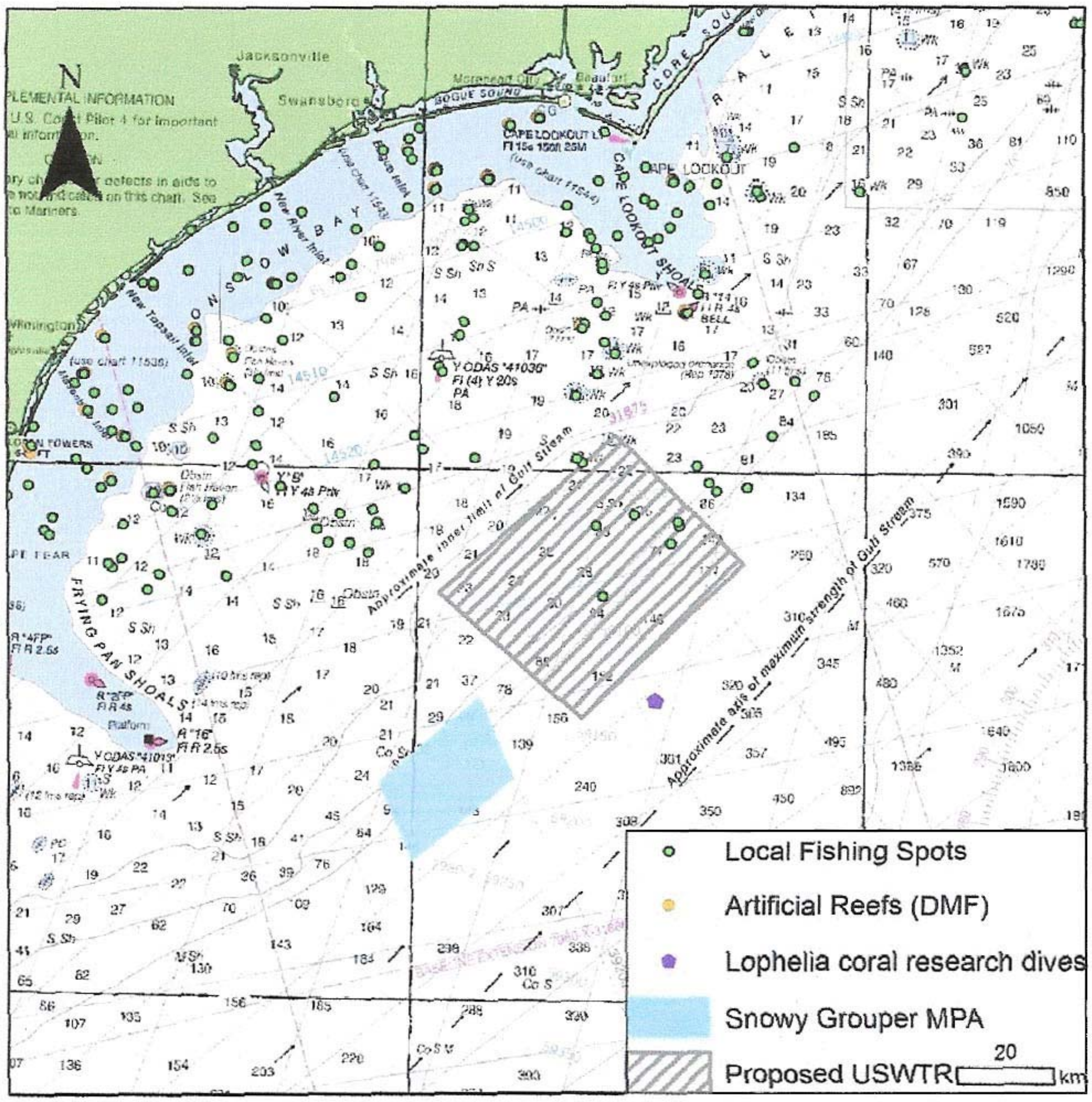

Figure 1. USWTR Alternative A in Onslow Bay. This map includes community knowledge of local fishing spots (demersal and pelagic), data from research dives confirming the presence of *Lophelia spp.* coral, and the recently designated Snowy Grouper MPA.

Table 1. Criteria for ranking research projects.

- Ease of study (rearing and handling of fish, likely statistical power)
- Cost
- Timely results
- Importance (socio-economic and biological)
- Acoustic vulnerability

Table 2. Mean rank of research projects by three working groups. Highest priority projects received a ranking of 1; lowest priority projects received a ranking of 3.

Category		Project	Mean Score
A—Resource Inventory	**A1**	Bottom mapping	1.0
	A2	Fisheries inventory	1.0
B—Mortality	**B1**	Swim bladder models	1.0
	B2	Larval LD50s	1.7
C—Auditory Effects	**C1**	Hearing capabilities	1.0
	C2	TTS measurements	2.3
	C3	Auditory damage	2.3
D—Non-auditory Effects	**D1**	Fish stress experiments	3.0
E—Behavior	**E1**	Small pelagics	1.3
	E2	Large pelagics	1.8
	E3	Soniferous Fishes	1.5
	E4	Demersal Fishes	1.7
F—Fishery Effects	**F1**	Other ranges	1.7
	F2	Socio-economics	2.3
	F3	Fleet monitoring	3.0
	F4	Monitor catch rates	1.3
	F5	Artificial reef project	2.3

Table 3. Species and families of key fishes from draft EIS comments (in no particular order), 2005.

a. *Sciaenidae* spp.	g. Billfish, Marlin (*Makaira* spp.)
b. *Carangidae* spp.	h. Snapper (*Lutjanus* spp.)
c. *Scombridae* spp.	i. Snowy Grouper (*Epinephelus niveatus*)
d. Bluefin and Yellowfin Tuna (*Thunnus* spp.)	j. Striped Mullet (*Mugil cephalus*)
e. Mahi Mahi (*Coryphaena hippurus*)	k. Menhaden and Herring (*Clupeids*)
f. Wahoo (*Acanthocybium solandri*)	l. Sharks, Rays, and Skates (*Elasmobranchii*)

Appendix A. List of participants at the Workshop on Mid-Frequency Sonar and Marine Fishes held at Duke University in Durham, NC, on April 19th & 20th, 2007.

Name	Affiliation
Joel Bell	US Navy
Andre Boustany	Duke University
Chip Collier	NC Division of Marine Fisheries
Pat Halpin	Duke University
Michele Halvorsen	University of Maryland
Mardi Hastings	Pennsylvania State University
Tony Hawkins	University of Aberdeen, Scotland
Elliott Hazen	Duke University
Lucie Hazen	Duke University
Jennifer Hill	University of Maryland
Keith Jenkins	US Navy
Joe Luczkovich	East Carolina University
David Mann	University of South Florida
Diane Miller	University of Maryland
Karen Montey	University of Maryland
Red Munden	NC Division of Marine Fisheries
Arthur N. Popper	University of Maryland
Jene Nissen	US Navy
Dave Noble	US Navy
Andy Read	Duke University
Amy Scholik	NOAA Fisheries Service
Frank Stone	US Navy
Jessica Tallman	US Navy
Lesley Thorne	Duke University
Magnus Wahlberg	Fjord & Baelt, Denmark and University of Southern Denmark
Lidia Eva Wysocki	University of Vienna, Austria
David Zeddies	University of Maryland

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10.	Thomas A. Rago Naval Postgraduate School Monterey, CA	1

11.	Tetyana Margolina Naval Postgraduate School Monterey, CA	1
12.	Chris Miller Naval Postgraduate School Monterey, CA	1
13.	John Joseph Naval Postgraduate School Monterey, CA	1
14.	Katherine Whitaker Pacific Grove, CA	1
15.	Frank Stone N45 Washington, D.C.	1
16.	Jay Barlow Southwest Fisheries Science Center, NOAA La Jolla, CA	1
17.	CAPT Ernie Young, USN (Ret.)	1
18.	Dale Liechty N45 Washington, D.C.	1
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20.	Kate Stafford Applied Physics Laboratory University of Washington Seattle, CA	1
21.	Sue Moore NOAA at Applied Physics Laboratory University of Washington Seattle, WA	1

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